RESEARCH NOTE

CONTRIBUTIONS OF THE US ARMY NATICK RESEARCH AND DEVELOPMENT CENTER TO THE OBJECTIVE MEASUREMENT OF THE TEXTURAL QUALITY OF MEAT*

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Abstract. Several approaches to the problem of objective measurement of the texture of meat, including modification of existing devices and development of new units, are presented. A mathematical–mechanical model is introduced which shows that some of the simpler tests presently used measure only part of the textural properties of meat; additional tests are needed to improve texture evaluation.

1. Introduction

A considerable amount of work has been done in recent years on the textural characteristics of meat and their biochemical foundations. The main reason for this, from the industry standpoint, is that texture, together with juiciness, is the most important quality attribute influencing consumer acceptability. The development of an objective test for texture measurement that could be used in purchasing as well as for the purpose of breeding better animals is of great commercial importance.

The purpose of this paper is (a) to survey some of our recent work on the methodology of texture measurement, together with some unpublished additions and improvements, and (b) to introduce a mechanical model simulating the myofibrillar and connective tissue structure of beef; we hope that the insight gained from this model will provide some new guidance in the development of a testing device for a more complete characterization of meat texture.

2. Automation of Texture Measurements

We have recently expanded our capabilities in texture measurement by automating the operation of an Instron Universal Testing Instrument (floor Model TT-DM), and by

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computerizing the processing of data while a test is in progress. Table I shows the different tests performed and the engineering properties computed.

TABLE I
Computer programs for the Instron Universal Testing Instrument

Rupture	Hysteresis	Stress relaxation	Creep	Sinusoidal cycling
Initial thickness	Sample thickness at the start of i_{th} cycle	Elastic and viscous moduli	Elastic and viscous compliances	Peak to peak stress
Ultimate strength	Stress at specified strain			Peak to peak strain
Ultimate strain				Complex modulus
Apparent modulus of elasticity	Apparent modulus of elasticity for i_{th} cycle			Phase shift
Strain energy				Apparent modulus of elasticity
Yield strength	Strain energy for i_{th} cycle			Loss modulus
Yield strain				
	Crushability index for i_{th} cycle			
	Hysteresis loss for i_{th} cycle			
	Cohesiveness			
	Relaxation index			

An Alpha 16 Minicomputer with 16 K memory is used, upon command by the operator, to select the type of test to be run, set the desired compression or penetration depth on the basis of the actual sample thickness, and after the completion of the test, to return the crosshead to the starting point in readiness for the next sample. The program which controls the movement of the crosshead takes advantage of the fact that the computer determines the sample thickness as soon as sample deformation begins (upon exertion of a slight pressure by the punch) and can use this information in subsequent instructions. This is particularly helpful in the performance of cycling tests. Using the standard manual procedure, when the "cycle" button is pressed the crosshead will move between preselected upper and lower positions for all cycles; if a new sample is introduced, its thickness has to be measured and the dials reset to achieve the same strain. With automation, all these operations are done automatically through computer instructions to the machine.

The above discussion refers to cycling for a constant strain calculated on the basis of the initial sample thickness. In our case it is also possible, if desired, to automatically *successive cycle*; this thickness will decrease among cycles due to the nonelastic recovery of the sample.

In other applications, the computer allows the operator to select part of the force-deformation curve for the automatic computation of the modulus of elasticity; if desired, modulus values can be obtained for more than one section of the curve. In addition, rupture and yield points are automatically computed by specifying in the program the percentage drop in force which the operator allows for each case. The results are displayed in printed form after the testing of a sample, at which point the operator may decide to accept them, or ask the computer to recalculate the different parameters from other sections of the curve before proceeding to the next sample. This makes it possible to make on the spot changes before, as well as after a test, according to experience gained with sample response. Upon completion of tests for a group of samples, the computer provides a statistical analysis of the data obtained.

The above automation allows a far greater number of samples to be tested and analyzed, with greater reliability in the data and conclusions drawn therefrom, than was previously possible.

3. Testing Devices

3.1. THE PUNCH AND DIE TEST CELL

The punch and die test cell reported recently (Segars *et al.*, 1975) is particularly helpful in practical applications, since the measurements obtained are independent of the geometry of the apparatus and of sample thickness. The cell uses standard Instron fittings and calibration procedures, and can be operated rapidly on only a small amount of material. This makes it useful in assessing the textural quality of different lots of raw and cooked meat where representative small samples can be selected; statistical analysis would dictate the number of samples required to satisfy a previously selected set of "accept/reject" conditions for the purchasing of meat.

3.2. THE NEEDLE PENETROMETER

The needle penetrometer, developed by our Food Engineering Laboratory and discussed by Tuomy in this issue (Tuomy, 1976), is a good example of a rugged and simple device which can give relatively good correlations between mechanical measurements on raw meat and sensory ratings on the cooked product.

3.3. THE POISSON'S RATIO DEVICE

The Poisson's ratio device is a new and, to a certain extent, unconventional approach to the measurement of meat texture. It measures the ratio of transverse to axial strain (Poisson's Ratio, μ_0) and the volume ratio, V/V_0, when a cylinder of meat is compressed between two parallel plates. As such, it provides information on the transverse or cross-linking forces which hold the parallel meat fibers together in the fiber bundle. One subsequent theoretical analysis (see section "A Two-Dimensional Viscoelastic Model for Meat" below), that two samples of meat may appear closely similar when tested by uniaxial compression and yet be quite different on the basis of the value of the Poisson's ratio. Standard Instron electronics and normal procedures for set-up and calibration are used, together with a strain gauge extensometer which can magnify minute transverse deflection by as much as one hundred times.

The Poisson's ratio apparatus, used in preliminary measurements on six muscles of cooked beef, showed considerable promise in correlations with sensory evaluation, in contrast to the modulus of elasticity which showed no correlation. When coupled with a suitable mechanical model, the obtained data may give a better understanding of the internal structure of anisotropic materials in relation to mechanical properties. However, a better sampling procedure to narrow the large standard deviations and greater precision in the measurement of μ_0 are necessary before final conclusions on the merits and limitations of this measurement can be drawn.

3.4. THE BENDING TESTER

The bending tester reported earlier (Kapsalis *et al.*, 1972) has been applied recently to the measurement of the mechanical properties (modulus of elasticity, bending rigidity, bending moment, curvature, and bending moment loss) of bologna, sausage and ham samples. Similar to plant products, the curves of the modulus of elasticity vs exposure time of sample strips decreased smoothly, suggesting a possible way for ascertaining the history or "freshness" of a particular sample. The relative homogeneity of these products made the measurements easier to obtain compared with plant tissues, since the thickness of each sample was more easily controlled.

A new general-purpose model of the above instrument, the Mini-Tester/UFT/3, combines tensile, torsion, bending rates and creep/relaxation testing with a variety of other tests, on a "micro" basis (load cell capacity 10–1000 grams and torque cell capacity 10–1000 microinch-pounds), at constant temperature.

4. A Two-Dimensional Viscoelastic Model for Meat

Parallel plate compression tests on beef often exhibit responses that do not conform to a simplistic understanding of the behavior of the material. A study by Segars *et al.*, (1974) dealing with the "mapping" of the textural characteristics of several beef muscles showed that tougher muscles gave lower values for the apparent modulus of elasticity than tender muscles. Since this modulus is proportional to the stiffness of a material, it was expected to increase with toughness. To explain the apparent anomaly, the two-dimensional viscoelastic model, shown in Figure 1, was developed.

The model was designed to produce the characteristic deformation observed when a cylinder of beef is compressed uniaxially, namely a swelling or "barreling" at its mid-section.

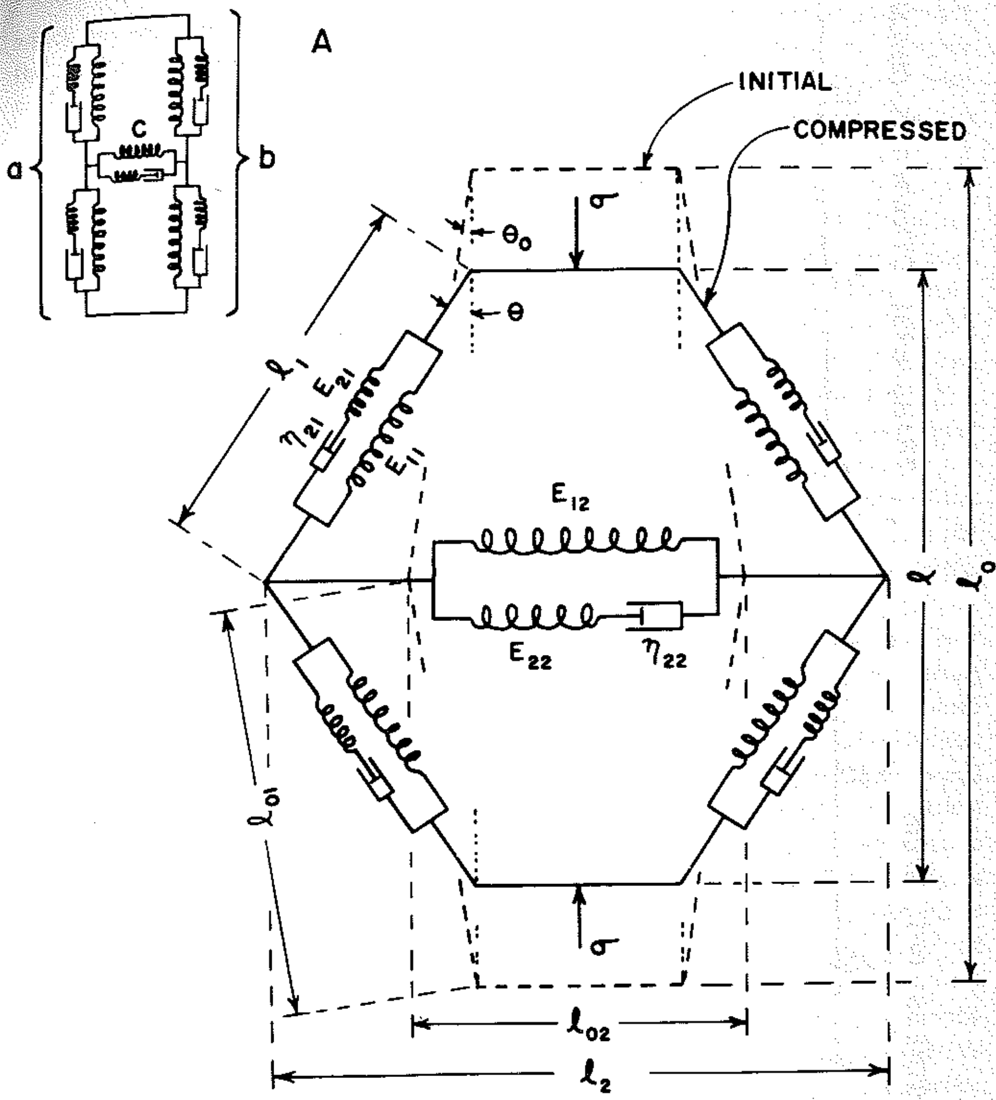

Fig. 1. A two-dimensional viscoelastic model for meat.

units on the left, *a*, represent, together, one fiber, as do the two on the right, *b*; the resultant of the connecting forces holding these two fibers together is represented by the horizontal unit connecting their midpoints, *c*. In the main part of Figure 1, this unstressed condition is indicated by dashed lines inclined at angle θ_0 to the vertical, whereas the fibers under stress σ are shown by solid lines inclined at angle θ to the vertical. The initial (unstressed) length of the model (sample) is l_0 and the initial separation of the fibers at their midpoints (sample diameter) is l_{02}. The initial length of each fiber unit is l_{01}. In the compressed state these lengths are shown as l, l_2, and l_1, respectively.

The first subscript assigned to an element specifies the particular part of the unit to

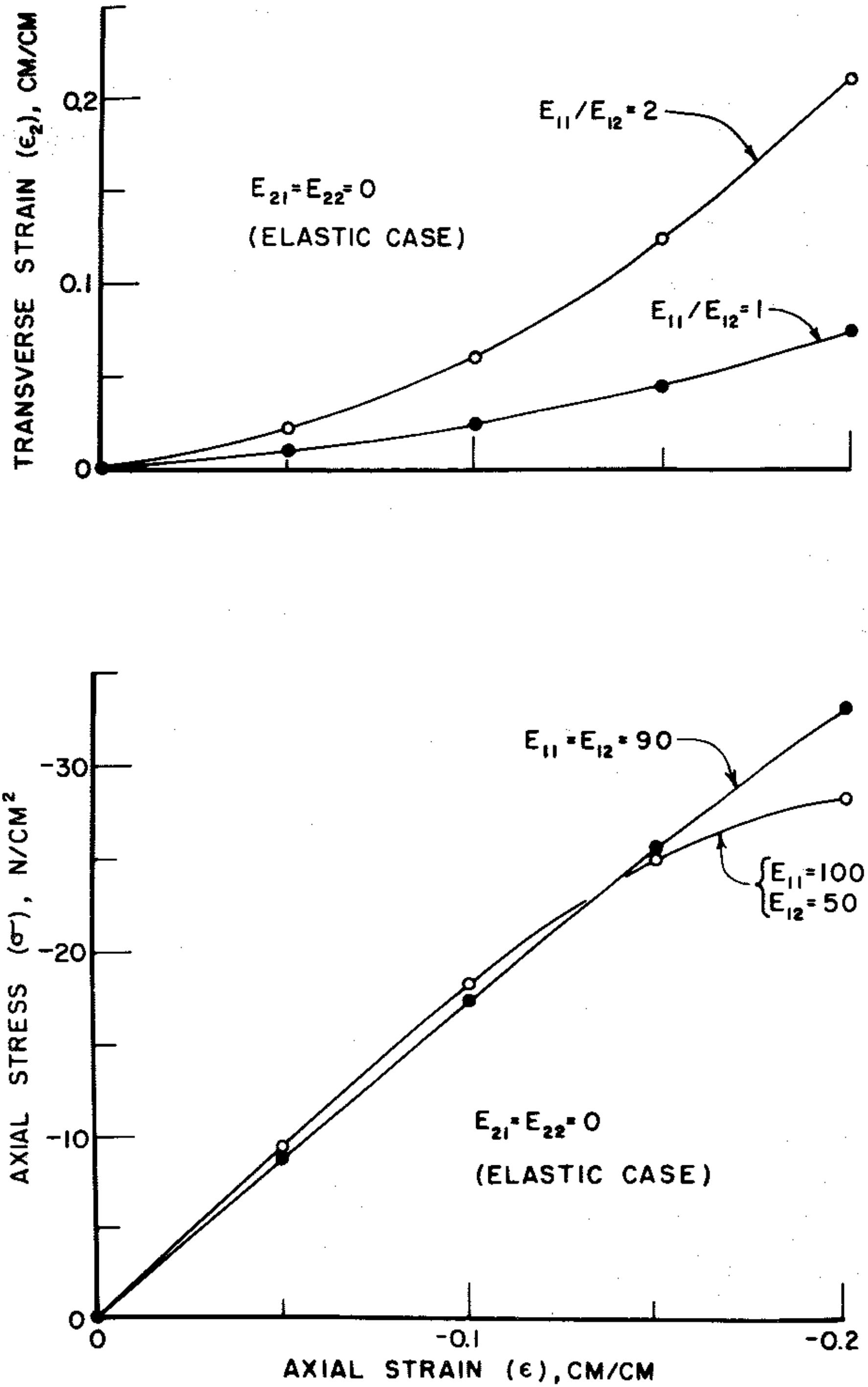

Fig. 2. — Stress-strain curves calculated from the mechanical model.

which the element belongs; number 2 signifies the viscous part (dashpot) in series with the spring, and number 1 indicates the linear spring in parallel with the previous combination. The second subscript assigned to an element specifies the part of the overall model to which the unit containing the element belongs; number 1 signifies that the individual element belongs to any of the four identical fiber units, whereas number 2 signifies that the element belongs to the horizontal connecting unit.

Figure 2, bottom, shows two stress strain curves calculated from the model for the elastic case obtained when E_{21} and E_{22} are zero. (When these spring constants are zero, the viscous dashpots need not move during compression or extension.) For axial strains up to 17 or 18%, these two curves are nearly identical and, therefore, the two samples represented by these curves would be considered similar. However, this is not the true situation since the spring constant E_{12} differs by 80% in the two samples. This shows that two samples differing significantly in internal structure may appear the same under uniaxial compression.

Figure 2, top, shows the transverse strain (ϵ_2) calculated for the same conditions as Figure 2, bottom. These two curves are quite different at all values of axial strain and thus provide a means of differentiating between the two samples. Data for a plot of this type are obtained with the Poisson's Ratio device mentioned previously.

It is quite probable that the human being, when chewing, can detect changes not only in the fiber strength tested axially, but also in the parameters associated with cross-linking forces. This places a limit to the magnitude of the correlation which can be obtained between sensory ratings and mechanical testing when only a single dimension is used.

Mathematical models are often used merely as a means of displaying experimental results, and as such they contribute little toward the understanding of either the textural properties of the material or the test method itself. Our model is not just an equation to fit experimental data, but it demonstrates that the transverse deformation plays a significant role in determining the textural characteristics of beef. It is possible that at least some of the discrepancy among different laboratories on the magnitude of the correlation coefficient between mechanical and sensory measurements is due to the incomplete mechanical characterization of the material as it is presently performed.

As mentioned in the discussion on the Poisson's ratio, our theoretical considerations resulted in the designing and construction of a device which can be used in actual practice.

The curves in Figure 2 represent cases for elastic behavior only. The equations describing the behavior of the general viscoelastic model, containing two viscous elements (dashpots), have been developed and are presently being programmed by our Data Analysis Office. These equations yield as a special case the "elastic" curves shown here by "freezing" the motion of the viscous elements and leaving only the elastic components to describe the stress–strain relationship. The computer program will calculate, based on the model, stress–strain curves that exhibit similarities to those obtained experimentally on several different foods and different cuts of meat.

Derivation of the equations of the complete model and the results obtained from the

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